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A REVIEW ON BRAKE LINING MATERIALS

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ABSTRACT

The quick growth of eco-friendly brake lining materials has necessitated the scientists towards expanded research and development of many safer suitable materials, because of the ban on the use of asbestos. As a result, brake manufacturing industries have started researching for frictionless brake lining materials. The past researchers focused on fiber reinforced polymers, non-metallic, semi-metallic, fully metallic and ceramics materials. Ceramics shows a great promise in the applications of friction materials. Most of the experimental output suggests that the selection of brake lining materials should be based on the experimental trial and error method rather than the theoretical method. In this review article, applications towards recent development of metal and ceramic matrix composites as brake lining materials have been studied.

KEYWORDS: Brake Lining Materials, Composites Materials, Metal Matrix Composites, Ceramic Composites & Tribo Evaluation

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Original Article

1. INTRODUCTION

Metal Matrix Composites reinforced with ceramics, a combination of metallic properties like ductility and toughness and ceramic properties like better strength and, lead to greater mechanical and thermal properties. Curiosity in Metal Matrix Composites in the following applications like aerospace, automotive etc., have been increased in previous five years. Finally, forced to re-produce microstructures and properties due to relatively inexpensive reinforcements and development of various processing routes [1]

Friction materials are heterogeneous and are composed of a few elements, which are used to prove friction property at minimum and maximum temperature, increase life span, mechanical properties and minimize porosity and noise. Tribological behavior study focuses on wear resistance, friction, and lubrication between interrelating surfaces relative to each other. The application of brake causes friction between brake pads and rotating disc to stop the vehicle. The kinetic energy gets converted into heat energy during the braking process. So, the friction materials should absorb heat quickly and also should withstand high temperature with less wear rate loss.

2. SELECTION OF MATERIALS

The application of brake lining friction material selection in the field of automobile and other vehicles needs to possess the following performance criteria: a reliable, agreeable level of friction, good resistance to wear, and ample heat dissipation, minimum cost and if possible lightweight. A multiphase composite has been developed to meet the required properties as a single material cannot meet all of these factors.

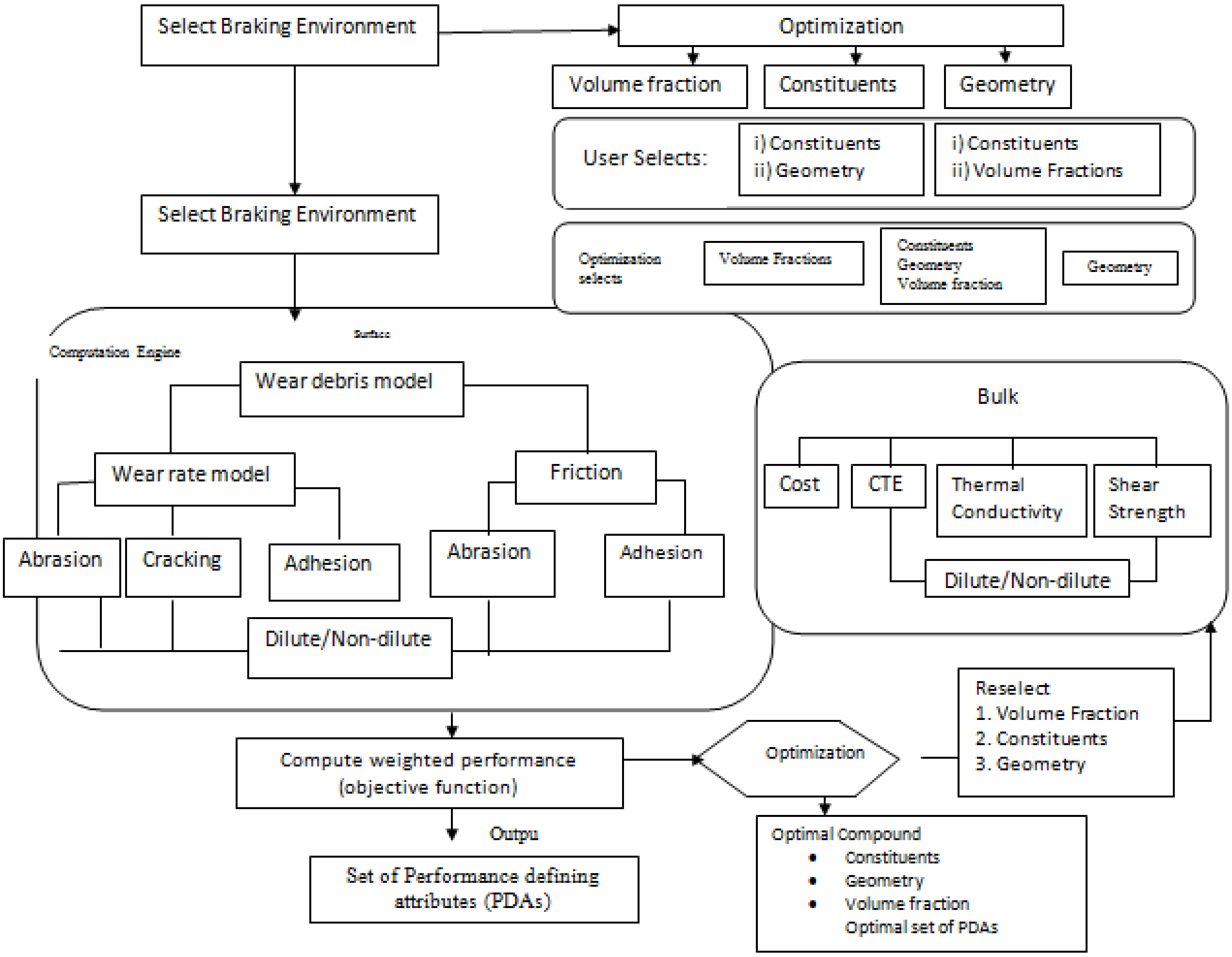

Figure 1: Intelligent Selection Approach of Material Selection for Braking Composites [2].

The figure 1 describes the two alternative paths like simulation and optimization for the material selection process. Simulation process provides the users specify the composite constituents, geometry and volume fraction. Optimization process provides a partial specification for optimal design.

3. MATERIAL SELECTION CRITERIA

Ceramic reinforcement selection criteria incorporate the following factors

- Elastic Modulus
- Tensile Strength
- Density
- Melting Temperature
- Thermal Stability
- Coefficient of thermal expansion
- Size and shape
- Compatibility

- Cost

4. TRIBOLOGICAL PROPERTIES EVALUATION OF THE FRICTION MATERIALS

It comprises friction and wears characteristics under various testing conditions, fade, and recovery and squeal studies.

5. TERMINOLOGY IN TRIBO-EVALUATION OF THE MATERIALS

- **Friction Coefficient:** It is the Ratio between frictional force to the applied load, and it is represented by *p*.
- **Fadet:** A temporary reduction of the braking effectiveness due to the loss of friction between the braking surfaces which results from heat is known as fadet.
- **Friction Peaking:** A process due to an increase in friction during or after high- temperature operation is termed as Friction picking.
- **Recovery:** When the brake lining cools once, it should be replaced repeatedly for its initial friction coefficient which is known as "recovery."
- **Water recovery:** The ability to recover from the loss of effectiveness due to exposure to water – Water recovery
- **Effectiveness**: It is defined as stopping efficiency which is expressed in number of forms like the coefficient of friction, airline pressure required, the length of space required for stopping the vehicle. The effectiveness is also measured as new or off rack, which means without any prior use, pre burnished means after little prior use, burnished means after moderate use, and faded which means used after elevated temperature (6).
- **Load and Speed Sensitivity**: Load is defined as the ability to maintain effectiveness at various load conditions and speed is the ability to maintain at various rubbing speeds. Except for semi-metallic, at high speed most of the materials show losses in effectiveness
- **Wear:** It is defined as the loss of mass or due to volume change (deformation) or performance change. It is generally expressed by (3, 4)

  $W = KP''VbtC$(1)

  Where, W (wear)

  K (wear coefficient)

  P (normal load)

  V (sliding speed)

  t (sliding time)

where *a, b* and c represent the set of parameters for a typical friction pair at a given temperature.

Various Phases of Brake Working

During braking process, velocity and deceleration varies with time. Figure 2 describes the variation of deceleration as a function of time as a general pattern. The four phases in the braking process are described as follows [5, 6]:

- **Initial Response Phase:** This phase starts from the inception of the actuation force to onset of braking force and it is represented by the line O-P
- **Pressure Buildup Phase:** The second phase begins at the point of onset of braking force to the moment until it reaches its stable value and represented by P-Q.
- **Active Braking Phase:** Third phase Q-R starts at the point of stable braking force till it ceases.
- **Final Response Phase:** The final phase takes place at the point of deactivation to the disappearance of the braking force, represented by R-S.

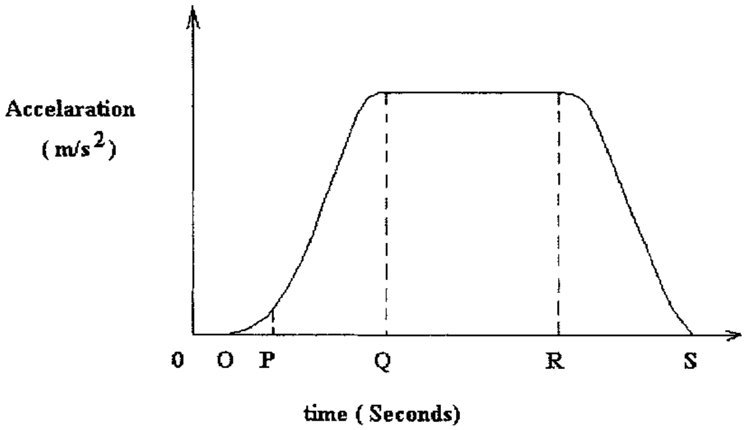

Figure 2: The Four Phases Occurring in the Braking Process [6].

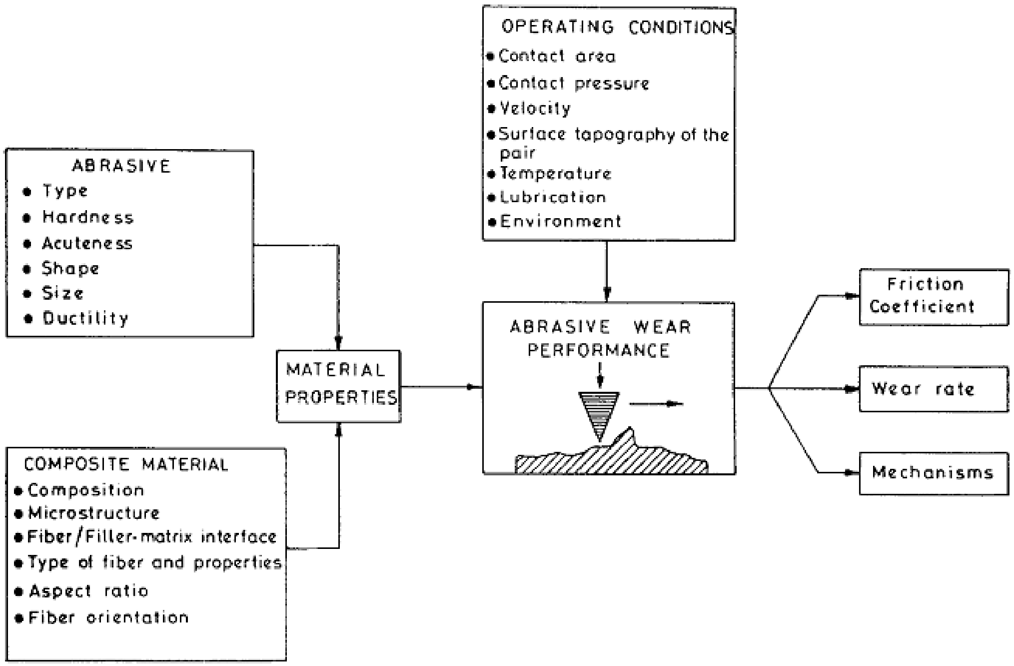

Figure 3: Parameters Influencing Friction and Wear Performance of the Materials Sliding in Abrasive Wear Mode. [7].

The parameters which influence the tribological behavior such as friction and wear performance of various materials were explained in the above figure 3.

6. AN OVERVIEW OF THE HISTORICAL DEVELOPMENTS IN BRAKE LINING MATERIALS

Asbestos are potentially exposed to the automobile mechanics through brake repair work. Brake lining and brake shoes material composition consists of around 50% of chrysotile asbestos encapsulated in a phenolic resin. Usage of such products in automobiles, buses, and other heavy equipment causes them to wear, releasing a fine dust of amorphous material together with very small fibers [8]. Asbestos is fibrous kind of materials, which contribute a major health hazard. Medically proved that, the asbestos causes four kinds of diseases like Asbestosis, Mesothelioma, Lung Cancer and Asbestos corns [9]. Asbestos based friction materials can't able to provide necessary tribological properties due to low thermal properties and mechanical properties. Due to negative effect of human health, nowadays asbestos brake lining has been banned in most of the countries [10].

7. FIBRE REINFORCED MATERIALS

Fiber-reinforced composites materials like carbon and glass fiber, and fiber reinforced plastics are widely used in the applications of both low and high technology engineering [11]. Fibers are used mainly for the material reinforcement and sometimes for the thermal stability [12]. The fibrous reinforcement plays a pivotal role in maintaining the mechanical and thermal properties of composites. [13].

The abrasive wear behavior of continuous fiber polymer composites has been investigated using pin-on-flat apparatus [14]. The results have been consolidated with three different materials like Fiber orientation, fiber material, and matrix material. The testing conditions are applied the load, sliding velocity and composite system. No significant change with an increase in wear rate shown for apparent normal pressure for the friction co efficient. However, there is no significant effect on tribological properties for the sliding velocity. No significant effect on friction co efficient found while increasing the contact area, whereas a slight decrease in wear rate observed.

The tribological property of a glass-fiber reinforced friction material with phenolic resin etc. was analyzed by using Chase Friction material testing machine [15]. Testing has been conducted at various temperature conditions. The wear test shows that coefficient of friction decreases for higher loads, speeds and temperature. On the other hand, specific weight loss was observed to be decreased with increase in load and speed whereas increases with increase in temperature.

An investigation of tribological properties and fade characteristics of carbon fiber reinforced phenolic friction materials discussed by Gopal in his paper [16]. The test was carried on Chase dynamometer. They concluded that carbon-fiber showed minimum wear resistance and higher friction co efficient at higher temperatures comparatively than glass-fiber.

S.N. Kukureka et al., has investigated the friction and wear characteristics of fiber reinforced polymer composites in their experiment [17]. Three different types of fiber like aramid fiber, carbon fiber and glass fiber reinforced with polymer were examined with a twin disc machine. The experimental output proved that the coefficient of friction has been reduced significantly with both carbon fiber and glass fiber. And also, a significant wear reduction observed in fiber reinforcement composites against a metallic counterface tested by pin-on-disc wear tester.

Wang Youming et al., [18] have briefly discussed on the non-asbestos friction materials, which has fibrous reinforcement with the binder. They have investigated and concluded that the coefficient of friction is relatively higher at lower brake pressure than that at higher brake pressure on wear properties of brae pad and rotor. Also, modification of pad

compressibility will help to reduce the brake noise occurring at the low braking pressure, which is caused by the higher friction coefficient.

8. BRONZE METAL MATRIX COMPOSITES

A USA Patent has suggested the sintered materials like bronze in the application of brakes and clutches [19]. Bronze based sintered alloys have been recently used for friction and brakes under dry conditions, which also a replacement of asbestos-based friction materials [20]. Synchronizers, Clutches, brakes, and others friction devices have been used different materials for different machines and mechanisms. Materials like Bronze, steel, cast iron, and composites are few of them mostly used [21].

Adam Kurt et al., [22] have investigated the bronze based material for wear rate analysis through experimentation, where the test specimen is made through powder metallurgy process. They observed that wear rate was high in bronze based brake lining material, whereas the thermal conductivity was drastically reduced with high porosity with a significant increase in density.

Plain bronze and Al_2O_3 reinforced bronze based brake lining were investigated and a comparative analysis of friction wear properties was done [23]. Samples were tested on the grey cast iron disc which was compacted at 350 MPa and sintered at 820°C. An optimum wears behavior. The optimum wear behavior was observed and the addition of powder sampan decreased pressing density with the addition of Al_2O_3 was observed without any change in sintering density. The highest friction coefficient was observed with 4% addition of Al_2O_3 samples. However, 2% addition of Al_2O_3 samples shows stable friction coefficient. The highest wear rate has been observed without the addition of $Al_2O_{3..}$

Radhika et al., [24] have investigated the mechanical properties and wear characteristics of LM25/SiC/Al_2O_3 hybrid MMC (Metal Matrix Composites). Specimens were prepared by varying the percentage from 0 to 30% by powder metallurgy process. Characterization test was carried out for both unreinforced and composites specimens whereas wear rate is analyzed by pin-on-disc machine. The experiment was conducted by fixing the sliding distance as constant at 1500 m and by varying the load and sliding velocity. The load was varied from 10 N to 30 N and sliding velocity 1m/s to 3m/s. The experimental results conclude that the reinforcement of composites with 30% shown higher tensile strength and hardness. However, wear rate was decreased with increase in weight percentage of reinforcement. On other hands, load increases wear rate seems to be increased and sliding velocity with constant sliding distance.

9. ALUMINIUM METAL MATRIX COMPOSITES

Comparing with other conventional materials Aluminium Metal Matrix Composites has been widely used in the application field of aerospace, automotive and marine due to its excellent properties and also much attracted by the research scholars for the few decades. [25].

Natarajan et al., [26] the wear behavior of aluminium metal matrix composites were investigated by comparing with the conventional grey cast iron of friction materials in their experimental study. Testing were carried out on a pin on disc machine and it seems to be the wear rate of cast iron is high with the applied load and sliding velocity whereas friction coefficient was constant. Also, the wear rate was comparatively and significantly low while comparing with cast iron in the application of brake drum. But for the application of lining material, wear rate gets reduced when sliding against cast iron. At the same time wear rate is high because of hard SiC.

Adel Mahamood Hassan et al., [27] have investigated tribological properties of aluminium matrix composites reinforced with Al_2O_3, Silicon carbide particles, and graphite. The investigation was done at room temperature at a pressure of 3.18 Mpa and sliding speed at 0.393 m/s on the pin-on-disc machine. Silicon Carbide particle addition with Aluminium alloys, the wear properties have been considerably improved whereas wear resistance found higher than the unreinforced aluminium alloys comparatively. However, the wear volume loss of composites was less than the aluminium matrix. The hardness and wear resistance also considerably increased for Al – 4wt% Mg alloys with the addition of copper alloys. Further, the addition of Silicon Carbide particles has significantly improved the wear resistance of Al – 4wt% Mg – Cu alloys.

Rongping Yun et al., [28] have briefly discussed the extensive evaluation for the brake materials. The evaluation has been carried by five different grade materials. Four samples A - D has been produced with various composition of materials like Alumina, natural fiber, Barite, phenolic resin, graphite etc., for testing tribological performance. Sample B constituting Phenolic resin 15, Graphite 8, Coke 6, Titanate 15, Wollastotine 10, Barrite 10, Natural fiber 25, Aramid pulp 5 and Alumina 6 Vol % has shown the best wear reduction brake materials and best highest dependence degree

The friction and wear behavior of aluminum alloy (Al-Si10Mg) reinforced with 9% alumina and 3% of graphite by stir casting method was investigated by Radhika et al [29]. The pin-on-disc tester has been used to perform the wear and frictional properties of metal matrix composites through Taguchi's technique. The experimental results proved that the sliding distance has high influence than the load and sliding speed. The following results were computed i) 46.8% of sliding distance have the highest influence on wear rate due to 31.5% applied load and 14.1% of sliding speed, however, 50% of the sliding distance, 35.7% of applied load and 7.3% of sliding speed have an influence on the coefficient of friction. Also when graphite is fused as primary reinforcement, it improved the wear rate of composites and when the alumina fused as secondary reinforcement, a significant effect was observed.

M. Manojkumar et al., [30] has worked on aluminum matrix composites by reinforcing fly ash particulates and graphite for the analysis of tribological behavior. Aluminum alloy 2218 with 4% graphite and 5,10 and 15% of fly ash particulates samples were prepared by stir casting process. Wear testing was done using pin-on-disc wear tester by varying the following wear parameter: sliding speed, applied the load, time and sliding distance. The most influence was found by sliding speed of 71.52% followed by 12.12% of load and 9.95% percentage of reinforcement. But 34.35% of sliding speed and 36.64% of load were found to be influencing the coefficient of friction for metal matrix composites. Wear rate of composites were found to be better than the unreinforced materials where the percentage increase with fly ash increases the wear resistance. Similar works were carried out by Mathan Kumar et al., [31] by reinforcing the Al 2618 matrix material with SiN (Silicon Nitride), AlN (Aluminum Nitride) and ZrB (Zirconium Boride) of various weight percentages through stir casting technique. The experiments were conducted at various conditions such as temperature, load, velocity and sliding distance. Influence of mechanical behavior, Tribological behaviour and percentage of contribution were analyzed by Taguchi technique and ANOVA and the best results are optimized. The tribological characteristics were minimized and maximum wear resistance achieved for all output conditions. $0.000523mm^3/m$ of minimum wear rate achieved and the process parameters were influenced by 8wt% of composites at 200°C for 10N load, Velocity 5m/s and sliding distance 2000m.

10. CERAMIC MATRIX COMPOSITES

Recently, an alternative material for the asbestos-based has been developed by ceramic particulate added powder metallurgy materials in the applications of automotive friction materials [32].

A considerable attention on advanced ceramics for wear properties in the literature for 50 years.[33–40].

For the few decades, Ceramics, metallically bonded ceramics (non-metallic solids) have been used for the purpose of Tribological properties.[41]. An improved abrasion resistance was exhibited by the ceramic particulate reinforced composites [42].

Tribological properties of plasma sprayed yttria stabilized Zirconia coating which was prepared by nanostructured powder were studied and compared with commercially available powder. [43] The optimized parameters were examined under sliding against 100C6. The nanostructured powder coatings and conventional powder have shown same friction of coefficient whereas wear resistant was almost reduced by one fourth in nanostructured coatings, comparing with conventional powders.

Tribological study on Aluminium alloys reinforced with hard ceramic particles, short fibers etc., were investigated in their study [44]. Aluminium alloys possess good mechanical and physical properties whereas it is extremely poor resistance. The results conclude that the Aluminium composites provided up to 60% weight reduction than cast iron. The wear rate was decreased with increasing reinforcement content for Metal Matrix Composites under both sliding and abrasive wear.

Yafei Lu et al., [45] have discussed the role of ceramic abrasives (ZrO_2, SiC etc.,) in brake friction composites. They have observed in their study that without abrasives the brake friction composites shows lower tribological property. With the addition of abrasives to friction composites, the friction coefficient and wear can be enhanced and the hardness of abrasives is a most important factor which affects the friction performance.

Metal Matrix composites have wide applications in industries like automobile, aerospace etc., because of its high strength and stiffness. Uniform distribution in the soft matrix phase with reinforcement phase of hard ceramic particles or fibers is also to improve the mechanical and tribological properties. [46]

Ouyang et al., [47] have investigated for various chemical compositions with the variety of self-lubricating ZrO_2 (Y_2O_3) matrix composites. He used BaF_2, CaF_2, Ag, A_2O, Cu_2O, $BaCrO_4$, $BaSO_4$, $SrSO_4$ and $CaSiO_3$ as additives incorporated with the ceramic matrix. At room temperature of 800°C using a ball-on-block friction and wear tester sliding against alumina ball, the evaluation of potential as effective high – temperature solid lubricants was conducted. A comparative study has been carried out with $ZrO_2(Y_2O_3)$ matrix composites in the presence and absence of graphite or MoS_2 under identical conditions. From the experimental outputs, he concluded that TZ3Y20A ceramics has 1.15 of high friction coefficient and 2.20×10^{-4} mm^3/Nm of large wear rate at 800˚ C. Also friction reduces at low temperatures by the addition of graphite and MoS_2 with TZ3Y20Aceramics. When theZrO_2 (Y_2O_3) matrix composites incorporated with CaF2-BaF2-Ag, BaCrO4, BaSo4 and $SrSO_4$-$CaSiO_3$ exhibit 0.2-0.4 friction coefficient and 10^{-5} to 10^{-6} mm^3 /Nm wear rates of room temperature to 800°C. Whereas TZ3Y20A-50$BaSO_4$ composites exhibit 0.33 friction coefficient and 4.72×10^{-6} mm^3/Nm of wear rate at 800°C. Finally the ZrO_2 (Y_2O_3) composites with $SrSO_4$ has shown less than 0.2, low steady-state friction coefficients and 10^{-6} mm^3/m order of small wear rate at room temperature.

11. ZIRCONIUM MATRIX COMPOSITES

For attaining the desired level of friction and effective hardness of the particles in the application of brake linings, Wide usage of various forms of oxides and silicates like Zircon, alumina, quartz, magnesia has been noticed [48].

Cho et al., [48] have investigated on brake lining materials for the effect of Zircon particle size on the friction behavior and wear resistance. He has analyzed with four different particle sizes of 1µm, 6µm, 75µm, and 150µm. The experiment was carried on pad-on-disk friction tester and concluded with his work that coarse Zircon particles produced a stable friction film and excellent friction stability whereas the fine Zircon particles generate transient friction film and excessive wear with poor friction stability.

Daoud et al., [49] have investigated in their research the impact of load and speed on the tribo properties of brake rotor made of sand cast which is made of A359-20vol% SiC particle composites sliding against automobile friction material. The experiment was carried on pin-on-disc apparatus. The A359 – 20 volume percentage of SiC particle composites form rotating disc whereas automobile friction material act as pin. The results were compared with the commercial cast iron brake rotor. He concluded in his results that the wear rate decreases when the load increases from 30–50 N, whereas increased for the load 50–100 N. Also the wear rate seems to be decreasing with increasing speed. The wear rate of composites was found to be high while comparing with cast iron at the speed of 3 to 9 m/s and 30 N loads. But still the wear rate increases significantly as the load increases till 100N. However, the wear rate seems to be reduced when the friction material was sliding against composites for the load 30–50 N whereas it increases with increase in load from 50–100 N. Alternatively the wear resistance seems to be decreased with increasing speed. At other end, the coefficient of friction composites and friction material decreases for all sliding speeds. And for the load range of 50 – 100 N with the increasing speed. No significant effect on coefficient of friction was found.

Manjunath et al., [50] have studied LM6 alloy matrix composites manufactured by die casting technique in which LM6 alloy matrix composites was reinforced with the silicon carbide. The experiments were conducted by changing the addition of particulate by weight fraction and mechanical properties like strength, ductility, toughness and wear resistance were analyzed. The results conclude that increase in silicon carbide has increased the tensile property but toughness decreases with Increase in silicon carbide. The composites showed a small increase in wear rate.

12. COPPER MATRIX COMPOSITES

At the friction interface, owing to its thermal diffusivity addition of copper alloys are mainly used. It is also familiar to maintain the coefficient of friction level at elevated temperatures. [51] In the matrix of sintered materials, Copper and iron are mostly used as the main metals forming for the purpose of friction [52].

Handa and Kato [53] investigated the impact of three fillers namely powders of Copper, CSNL and barite in their research. Also they investigated tribo properties on a reduced scale tribometer based on phenolic resin. Results were proved that fade resistance increased wear resistance decreased due to the inclusion of copper powder.

Mukesh Kumar et al., [54] have evaluated the tribological behavior and performance of friction materials with metal content and compared with and without any metal content. The tribo evaluation is done using inertia brake dynamometer testing whereas the performance properties were carried as per industrial schedule. He conducted the various test like burnishing, effectiveness, emergency brake test etc., under various test condition for the evaluation. From the

experimental results, he concluded that the performance properties have been improved due to the presence of metal contents and best tribo behavior for copper-containing composites. The composites without metal powder shows poorest tribo behavior and also poorest performance properties.

Gultekin et al., [55] have investigated the tribo behavior of brake pads using pin-on disc trobometer with sintered copper matrix composite reinforced with graphites against cast Al-Si/SiCp brake disc and effects of load on friction. For experiment, the aluminium metal matrix composites as disc and graphite reinforced copper matrix composites as the brake pad. From the investigation he concluded the following results i) the wear resistance of brake disc and pad is high due to the presence of significant amount of material transferred from brake couple materials. ii) The friction coefficient decreases with increasing load iii) the friction coefficient varies from 0.2 to 0.45 due to the presence of graphite content for applied load and sliding distance.

Ram Prabhu et al.,[56] have studied the composites made of commercially pure powders of copper, tin, SiC, Barium Sulphate, Graphite and Zinc Stearate for tribological behavior and wear resistance evaluated by powder metallurgy process. Two types of multilayer hybrid composites and two types of single layer composites were used for experimental evaluation. The test report shows a significant improvement in mechanical properties due to the presence of a layer structure in the composites.

13. INFLUENCE OF PROCESS PARAMETERS

The manufacturing conditions of brake lining materials are mostly affected by the thermal properties.[57] Doi et al. [58] have stated that the particles shape and size plays a vital role in designing of brake lining materials.

RukiyeErtan et al., [59] have investigated the composition of brake lining materials experimentally and also analysed tribological properties, the effects of manufacturing parameters. The aim of the research is to obtain optimum manufacturing parameters for tribological behavior test carried on Chase type friction tester. They have found that the manufacturing parameters considerably improved the tribological behavior.

Sai Balaji et al., [60] have analyzed the temperature rise between 150°C to 400°C during brake application using Thermo Gravimetric Analysis. The experiments were carried out for three different formulated samples varying the percentage of Aramid, Cellulose and Acrylic fibers during friction testing. The experimental results concluded that the organic fiber leads to increase in friction coefficient but hardness and specific gravity has reduced due to organic fiber content.

Nagesh et al., [61] have prepared five different brake pad samples with the various composition in weight percentage using powder metallurgy process to determine friction characteristics using pin-on-disk test machine. The results were compared with commercial brake pads. The constituents of commercial brake pad were steel wood, vermiculite, natural graphite, carbon black, ceramic fiber and resin. By varying, the percentage of frictional materials such as iron oxide, barites, artificial graphite, mineral fiber was newly formulated specimens was prepared. The experimental outputs proved that Sample S2 (Steel wool, Vermiculite etc.,) shows high wear rate and stable coefficient of friction. Sample S4 (Iron oxide, Barytes etc.,) shows the slightly high coefficient of friction of about 0.45 due to abrasives contents. Sample S2 and S4 samples were equivalent to existing brake pads and also economical.

Sekar et al., [62] have discussed the effects of shear strength and tribological properties of A356 alloy reinforced with Al_2O_3nano particles of 30 mm by varying the percentage from 0.5 to 1%. Tribological properties were carried out at a

load of 10,30,50N, sliding speed of 0.534 m/s and sliding distance of 1100m in dry condition on pin-on-disc test. Metal Matrix Composites with 0.5 and 1% of Alumina nanoparticles shows highest shear strength than the base alloy, also it exhibited less wear loss and MMC with 1% Alumina shows the least coefficient of friction.

14. CONCLUSIONS

The recent research on the development of brake lining materials has been successfully done on various matrix composites under various process parameters and techniques. All the investigation proved that different matrix composites have shown a significant improvement in tribological properties and mechanical properties. From the overall review of various experimental outputs of different matrix composites, following points are summarized as follows:

- A new formulation of metal matrix materials has led to the development of eco- friendly brake lining materials.
- A major part of the role has been played by reinforcement for enhancing the tribological properties and material characterization.
- All research work has been proved that the composites materials have the capability of reducing the wear resistance; produce frictionless brake material sand increases mechanical properties, possess high thermal resistance.
- Some researchers have proved that the particle size, process parameters, and manufacturing techniques also have the major influence on tribological characteristics.

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